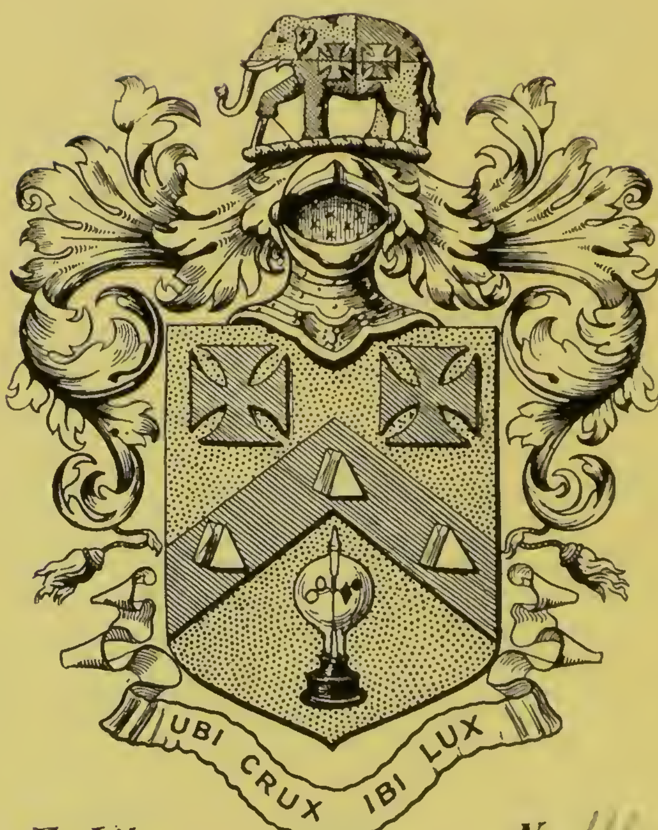
NOTES ON CHEMICAL RESEARCH

W. P. DREAPER



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SIR WILLIAM CROOKES, D.Sc., F.R.S..

Notes on Chemical Research. By W. P. DREAPER, F.I.C., F.C.S. London: J. and A. Churchill. 1913.

THE text of this book has been reprinted from the *Chemical World*, in which it appeared last year in the form of a series of articles. The author discusses the personal qualifications necessary to enable a man to become a successful investigator, basing many of his conclusions upon the consideration of the lives and work of the great pioneers of chemical science. He has valuable suggestions to offer relating to the choice of a subject, both for research work in pure and in applied chemistry, and he gives excellent advice upon the reading of original articles and upon the authorities to consult for special information. The student who is working in a laboratory will gain by reading the book even if he cannot immediately put its precepts into practice. It will widen his outlook and give routine work, which might otherwise become monotonous and wearisome, a new aspect. (C. N. 4. 4. 13)

NOTES ON
CHEMICAL RESEARCH

MICHAEL FARADAY

TEXT-BOOKS OF CHEMICAL RESEARCH AND ENGINEERING

NOTES ON CHEMICAL RESEARCH

AN ACCOUNT OF CERTAIN CONDITIONS WHICH APPLY TO ORIGINAL INVESTIGATION

BY

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"Whoever could make two grains of corn, or two blades of grass, to grow upon a spot where only one grew before, would do more essential service to his country than the whole race of politicians put together."—*Swift.*

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PREFACE

MODERN science is based on the record of past investigation. This condition must therefore apply to chemistry, which is essentially an experimental science.

While original investigation remains an important factor in further progress, those engaged in any branch of science must have some knowledge of the general conditions under which such work has been undertaken in the past; and realise that it can only be undertaken by an investigator who has reached a stage in his development, at which he is able to think in terms of his science. He must become one with his work.

A mere knowledge of facts and principles, however complete in itself, is an insufficient equipment. A student may possess this, and yet occupy an isolated position. Many who seem well qualified by examination, or otherwise, fail in the initiation of such work, for they cannot make practical use of such knowledge and apply it to the further investigation of natural phenomena.

Other important conditions are involved in work of this nature. They are of little account in the absence of this controlling factor, which brings with it the power of *seeing into things* and realising the relative importance of observations made under definite conditions, and the correctness, and value, of any deductions arising from the same.

An attempt has been made to state, in general terms, the conditions which have been regarded as essential to success. The influence and importance

of the results already obtained by investigation have been generally noticed, and the recent advance in the conditions of training and facilities for research has not been overlooked.

The student must give special attention to the theoretical side of his science, and train his mind to discover in the recorded work of others, the conditions which have led to success ; examining the why and wherefore of each step, as it occurs in its natural, and therefore logical, sequence.

Such intangible factors as mental outlook and personal qualifications can only be dealt with in a general way, and then chiefly by reference to the experience of past investigators. It is equally difficult to determine, from available data, to what extent these faculties may be developed, or actually created by training. It is certain, however, that when these are present, the battle has yet to be fought out in the laboratory, or works.

An insight into such matters may be gained by examining the results obtained by others. A general knowledge of the conditions involved must be possessed by those who wish to succeed in the conduct of such work. In some cases, a survey of past investigation may be the simplest way to secure this end. A search of this nature will often suggest the need for further investigation, and supply the investigator with suitable subject matter for research. This end may also be secured by the study of abnormal phenomena, which may from time to time be observed in actual practice, particularly when these occur on an industrial scale.

A satisfactory knowledge of the conditions which govern such investigation is of importance to the general chemist. It cannot fail to influence the conduct of routine work, and instil into it a new meaning.

Generally speaking, the laboratories of our lead-

ing colleges and technical institutions offer facilities for the conduct of such work. When these are examined, and considered, in conjunction with those which exist elsewhere, it is evident that still more attention will be paid to investigation of this nature. This must greatly influence, if not determine, the future of our industries, as well as our position in the scientific world. That this fact is being more and more realised is sufficiently obvious.

It is hoped that the publication of this small work may induce the student to realise at an early stage certain essential conditions which must necessarily govern his future work, and emphasise the value of those personal qualifications which can be recognised as influencing the work of investigators in the past.

THE AUTHOR.

LONDON.

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NOTES ON
CHEMICAL RESEARCH

CHAPTER I.

Historical Review and Nature of Research.

> "The chymists are a strange class of mortals impelled by an almost insane impulse to seek their pleasure among smoke and vapour, soot and flame, poisons and poverty, yet among all these evils I seem to live so sweetly, that may I die if I would change places with the Persian King."
>
> (*Physica Subterranæa.*)

Our knowledge of natural phenomena, and therefore of chemistry, and the experimental sciences which have sprung from it in the course of its development, is confined within the range of our senses. In certain cases this natural limit has seemingly been extended by the aid of such instruments of precision as the spectroscope or microscope. The application of mathematics, when applied to the extension of our knowledge in this direction, may also be said to have served a similar purpose.

The results recorded from a study of the conditions which control, represent, or indicate in accepted terms, such changes or phenomena as have been observed, have been brought to a state of order, and expressed in terms of so-called laws. In this way certain phenomena

have been symbolised in terms of definite comparison. A classification of the results obtained has proved of first importance to the investigator in the further extension and study of his science. In this way the work of the past is under continual revision and criticism.

It may not be possible to determine how far the conclusions arrived at represent the ultimate conditions of energy and space; or whether these can be expressed in terms of our system of thought. Facts and phenomena may be so distorted in such expression, or so partial in their nature, that the conclusions arrived at may only represent actual fact as a shadow on the wall represents the substance.

There is, however, a growing sense of security in the value of the methods employed, and a belief that they in some way indicate the nature of actual conditions, even if they do not represent them in absolute terms. This conviction is based upon the nature of the evidence brought forward by the practical investigator.

Speculations as to ultimate conditions must have no adverse influence on the value of the experimental method in the student's mind. Rather should the contrary effect be produced. The programme before the chemist is sufficiently definite. Investigation must be continued from the position it occupies to-day, extended in every possible direction by the direct aid of experiment, and carried to its utmost limit.

Knowledge obtained by the aid of experiment is said to have been obtained by a process of induction. This may, within certain limits, be utilised to a further extent by the process of deduction. This attempt to extend knowledge on lines of certain theoretical conclusions, by suggesting the nature of results which may reasonably be ex-

pected to follow under conditions somewhat equivalent to those already dealt with, has a definite value.

Thus future results may to an extent be anticipated, and results inferred or foretold by such utilisation of direct knowledge. By this means important conclusions have been obtained. The existence of unknown elements and their properties have been deduced and subsequently verified by experimental evidence.

In this and other directions such deductions have been fully justified as a means towards progress. Conclusions based upon theory have been of great value as stepping stones to a further advance, and the bridging (in a temporary way) of gaps in the chain of experimental evidence.

At the same time a sharp line must be drawn between knowledge obtained by these direct and indirect methods, which may be defined as of the first and second order respectively. When an investigation is partly based on theoretical speculations, the results arrived at must be of a convincing nature, if they are to be generally accepted. They must be continually subjected to examination in the light of further experimental knowledge, being compared with any new facts which may support or oppose those originally set out.

In the absence of any definite plan of action a preliminary scaffolding based on theory must sometimes be erected in advance. When the experimental results obtained do not conform to or uphold this, it must be correspondingly modified, or even replaced, by one which agrees with the further facts disclosed by the investigation.

Such use of theory has been fully recognised. It serves a purpose in indicating new lines of research, which the results obtained by the investigator must subsequently confirm or destroy.

The relative value of induction and deduction has been much discussed. The successful investigator is prepared to make every use of both methods, verifying all deductions by direct experiment (where this is possible) as the research opens out and progresses towards its logical conclusion.

Chemical research is generally confined to the study of changes which matter undergoes under definite conditions of strain, with an examination of the products obtained and the conditions ruling at the time; this is completed by the setting out of the results obtained in terms which suitably express such actions.

A record of such facts has been defined as crude knowledge, which in turn is known as the raw material of science.

Knowledge is regarded as generalised or empirical. In the latter case it has not yet been expressed in terms which can be recognised, or referred to any known cause or law. Facts of this nature are considered useless for the purpose of science, although they may have a definite value in the arts and manufactures. Where these exist there is a further call for an investigation of unrecognised conditions. Many investigators pay special attention to these reactions, for they naturally indicate suitable subject matter for further research. In the industrial world such phenomena are constantly met with, but are in many cases lightly passed over. Thus promising material for research is too often neglected for want of a suitable opportunity for investigation. As this is met with in the works rather than in the laboratory, this undesirable position is still prevalent in many directions. Under the stress of circumstances the connecting link between the passing observation and the means to examine it in detail is often absent.

Sufficient attention is not paid to this important source of subject matter. Those who have followed up investigation on such lines, recognise its special value as an aid to industrial advancement and as a suitable training for the student.

HISTORICAL REVIEW OF PAST INVESTIGATION.—Chemistry as an exact science dates back to the middle of the seventeenth century, although it has been practised for thousands of years in a purely empirical manner.

It may possibly have originated with the manufacture of alcohol by a process of fermentation, and the natural control of such operations ("History of Chemistry," Thorpe, 1909). It is said to have been manufactured in China in the year 2220 B.C. Dyeing, the production of leather, the working of metals and alloys are also of great antiquity. There is direct evidence that these operations were conducted with skill by the Egyptians from very early times.

The speculations of Jean Rey, in France, and of Descartes, foreshadowed the birth of systematic investigation on experimental lines.

In this country research may be said to date from the formation of the Royal Society, and the immediate results which led up to this important event. In 1661 Robert Boyle published the "Sceptical Chemist." In this he outlined a new philosophy. This investigator, with the help of certain supporters, sought to cultivate the system which was at the base of his suggestion. The Invisible College, based on a conviction "that they were satisfied that there was no certain way of arriving at any knowledge, unless they made a series of experiments upon natural bodies," was founded. Boyle's personal work set a high standard for such investigation. A consideration of his discoveries, experiments and conclusions, is

of extraordinary interest to the student. His conception of an element is that in general use to-day; but his great service to science and learning generally consisted in the new spirit he infused into chemistry, which at once lifted it into the plane of a great science. It no longer remained the handmaid of medicine, as practised in those days.

As a result of this advance in method, chemical research was seen to offer great possibilities. The Invisible College became the Royal Society, the charter of which was obtained in 1662.

Robert Boyle's conclusions were destined to influence the entire scientific world, and to give rise to modern chemistry. To the close ring of mere thinkers the experimental basis of science was definitely proclaimed.

An examination of Boyle's work brings with it a certain realisation of a power of concentration and determination which are factors in all original work. Its lasting influence emphasises to a degree the importance of knowledge based on direct experiment, and indicates the respect which such work must always command. It shone out as a bright star in a firmament of make-believe. It still remains as an example to those who have the advantage of working under modern conditions. Boyle's method has dominated research and become the recognised basis of all scientific knowledge.

Lemery followed in Boyle's footsteps, also insisting that chemistry was a science of observation. He suggested the natural division of chemistry into organic and inorganic branches. Boerhaave published his "Elementa Chemia" in 1732. This work greatly influenced the thought of the period. The investigations of Priestley and Cavendish, which followed, are too well known to demand more than passing notice. With those

of Lavoisier, Dalton, Berzelius, Prout, and Davy, they bring us to the early days of the nineteenth century, when Nicholson and Carlisle first decomposed water by the aid of the voltaic pile. This observation received great attention, deepening the rising interest in this progressive science, and materially assisted in its general development.

Thus a rapid advance in chemistry followed the recognition of the unique value of direct investigation by experiment. Boyle's suggestion and its definite acceptance as the only source of knowledge of natural phenomena has led up to the present position of modern chemistry and the experimental sciences.

By an examination of the sequence of developments, which followed as a direct result of the general acceptance of this idea, the student will realise the supreme power and value of research, and measure its direct influence on the progress of civilisation. This suggestion of continual progress must be the underlying thought. It must guide the investigator in all his ways and find expression in any work which has a permanent value. Thus, progress by research has become the hall-mark of science, and is rapidly occupying an equally definite position in the industrial world.

The historical side of this development may be followed in a recently published work, "The History of Chemistry," by Sir Edward Thorpe (1909). This, with its excellent bibliography, may form a suitable introduction to the subject. For further details the other standard works on this subject may be consulted. The student should also be acquainted with the Alembic Club Reprints and Ostwald's "Klassiker."

When considering this general position the beginner must guard against the conclusion that startling discoveries result from a casual observa-

tion on the part of some investigator. This is not so. Many previous investigators had probably overlooked these same phenomena. Only a trained observer can appreciate their value, and take advantage of their occurrence.

It may be safely assumed, that under modern conditions, successful investigation has its origin in a basis of the closest reasoning, and only when this is accompanied by a careful survey of previous work, and a full consideration of the best conditions of working, can a successful issue be anticipated.

This view was certainly held by Faraday, when he said "that the world little knows how many of the thoughts and theories that have passed through the mind of a scientific investigator have been crushed in silence and secrecy by his own severe criticism and adverse examination, that in the most successful instance not a tenth of the suggestions, the hopes, the wishes, the preliminary conclusions have been realised."

It has been generally agreed that no scientific discovery can with any justice be considered as due to accident; knowledge and training are essential before results which are worth consideration can be obtained, or what is perhaps of more importance, their true significance realised. The young investigator will do well to accept this position without question. Experience can only confirm it. It is important to realise from the first that discoveries are laboriously sought for; that they are the result of a direct and patient search. Having realised this important point false hopes are destroyed, and additional value given to the results obtained. It will act as an incentive to the student to make full use of facts which are already available, and to increase knowledge in every possible way. It points to the only means by which success can be achieved.

The recognition of this fact is of great importance to the routine worker, for it indicates that there is always a reasonable chance of securing results by close observation. In standard methods of analysis the only safe means of detecting remaining errors, or inherent defects, is by a comparison of the results obtained on constant repetition. This often leads to improvement by modification in detail. Such results become immediately useful. They may even bring to light new problems of a comprehensive nature, leading to further investigation on more general lines. Thus each type of worker has special methods for securing an increase in knowledge, which may be obtained in this case by applying the methods of experimental investigation to the every-day operations of the laboratory.

In experimental investigation great attention must be given to detail. Where this is not fully realised, conclusions may be drawn from premises which are either incomplete or incorrect. When these are made use of, confusion and uncertainty will result.

In industrial operations this may well be disastrous. Much time has been lost in attempting to apply such imperfectly worked out conditions on a manufacturing scale. The effect on the actual investigator of such partial success, or failure, is equally unfortunate and may lead to a corresponding lack of confidence.

The natural difficulties which surround an attempt to increase the scale on which an operation is conducted are sufficiently formidable in themselves. The data obtained in the laboratory under the best conditions are often not sufficiently definite for such an extension to be carried out without subsequent investigation. New difficulties come to the surface. These have to be dealt with by further research.

All possible care must therefore be exercised in the initial stage, and the laboratory results examined and checked in the smallest detail. In this way the presence of difficulties introduced through want of attention is reduced to a minimum.

The need of a sound training in research, and the methods of conducting it, is self-evident. It is an essential condition to success. The only point remaining for discussion is how far such training can be imparted to a student under university or college conditions.

Definition of Research. — Experience has shown that it is difficult to define the exact nature of such work, and this has led to a good deal of uncertainty in the past.

Research has been defined as a "wrestling with nature, a striving towards the limit of attainable knowledge." In putting forward this definition, Gore held that it consisted of observation, study, and experiment, in varied proportions.

Discovery has generally been defined as "a passing from the known to the unknown." It is considered that this result is achieved in the following cases* :—

(1) When we perceive a new impression.
(2) When we observe a new fact.
(3) When we compare two ideas and observe a new similarity or difference.
(4) When we compare two propositions, and perceiving a similarity, or difference, infer a new truth.
(5) When we divide, or analyse, a compound idea, and perceive a new, or more elementary one.
(6) When we combine two or more ideas

* Gore.

together by an act of imagination, and perceive a new combination.

(7) When we permutate, or alter, the order of a new series of ideas, and perceive a new order.

When an attempt is made to define the exact relation between investigation and research it is difficult to arrive at a satisfactory result. The following definition recently set up to meet special conditions suggests, by inference, the nature of such difference :—

It is considered necessary that :

(1) Research as result of observation or experiment must result in the collection of new facts.

(2) It must involve an examination of the facts collected or phenomena observed, and the reduction of them to a form in which they constitute an addition to knowledge.

It has also been held for practical purposes of definition "that work published by one of the learned societies may be treated as research."

W. M. Gardner has defined research as "a logical and original investigation inspired by imagination and directed by special knowledge."

Chemical research has been divided into two distinct branches, which deal respectively with investigation which has a theoretical or practical significance. Sir William Tilden has defined these respective spheres in the following terms :—

(1) The worker watches the operations of nature and puts questions in the form of experiments solely with the desire to find out her ways.

(2) Attention is given only to those laws, facts, and phenomena which can be made serviceable to man.

In the future this definition may require amending

in the implied suggestion that the division between these two classes is of a hard-and-fast nature.

Under modern conditions of industrial research the interests involved in many cases are such, that the conclusions arrived at have often far-reaching theoretical importance. The great advance which has taken place in tinctorial chemistry would not have been possible without the aid of those chemists who have followed up this development from a commercial and industrial standpoint.

As time goes on, this dividing line will become less marked, and such a definition may possibly lose its present significance. A fusion of interests will follow on a realisation of the extremely complex and increasingly important status and significance of modern industrial research. The connection between the two branches of pure and applied chemical research is already seen in the use made of theoretical knowledge of an advanced nature in industrial research, as in the actual working out of the attempt to fix nitrogen for industrial purposes by Caro and others, and the means thus offered for the establishment of many important theoretical conclusions.

If it were possible to discard the term research, and divide chemical investigation into the two main divisions of original and applied work, many of the past difficulties in definition and distinction might disappear; and with this condition a further advance might be observed in the relationship existing between the two branches of pure and applied science.

EXPERIMENT *v.* OBSERVATION.—The investigator must understand the distinction involved in this expression. Observation is defined as a mere recording of phenomena as they occur in the ordinary course of nature. When this course is changed by the intervention of personal thought, resulting in action, we are said to experiment.

These two conditions have been defined by Herschell as "passive" and "active" respectively.

An experiment differs from an observation in the fact that the specially introduced conditions determine or influence the direction and character of the results obtained. When considering this point the student may refer to "The Study of Chemical Constitution," by Freund (1904), Cambridge Physical Series, where the subject is treated in a manner which enables the influence of experimental evidence to be easily realised.

A final estimate of the relative value of observation and experiment is impossible under present conditions. It varies in different branches of science. It has not the same value in chemistry as in medicine, where observation is seemingly receiving increased attention at the expense of experiment. Observation has possibly a greater value in a new industry than an old one. It is still indispensable to the industrial chemist, and is being used with far-reaching results.

Its specific value is generally recognised. It is often a necessary, if preliminary, step towards investigation of a strictly experimental order.

Thus, the term empirical, when it is applied to the method of observation, does not always possess the adverse significance which is sometimes ascribed to it. By its aid early observers were able to carry on certain reactions on the industrial scale, long before the question of a scientific control was thought of, or any reasonable explanation of the actions involved could be given. Industry based on such practice was for long ages a determining factor in the advance of civilisation.

In certain cases where this condition still rules it must be regarded as an indication that the reactions involved defy the investigator's skill to explain them.

Thus it happens that complicated processes are in operation to-day which to a great extent run on empirical lines. The investigator must guard against adversely criticising such methods in cases where it is clear that the conditions of scientific control are not yet fully worked out, and empirical methods are still necessary. Industrialists must not be blamed if they continue the use of such methods against the time when it is clearly proved that alternative ones can be followed.

The value of observation on empirical lines can be best realised in the industrial world. In many cases it represents the only working method available. The value of the experimental method may be accepted as beyond all question, but the time has not yet come when the empirical method can be dispensed with in the industrial world.

There is an intermediate stage in the development of scientific investigation or progress, where, as Faraday has suggested, "ideas which may have a provisional basis on experiment are so often the shades of a speculation—impressions on the mind which are allowable for the time as guides to thought and research," although "often their apparent fitness and beauty vanish before the progress and development of real natural truth." The way of the investigator is one of successful application of thought or knowledge. It is not rendered less difficult by any fast definitions or preconceived ideas which may cramp thought and interfere with progress along lines of least resistance.

The industrialist experiences a certain satisfaction in those processes based upon observation, which have never failed to furnish him with definite results, even if their operation has not yet been explained in terms of modern scientific thought.

The advance of industry was securely fixed

on a basis of observation long before the experimental method was brought into action. It ruled supreme for long ages. Possibly its success accounted for a delay in the realisation of the value of the experimental method, which has now been fully demonstrated, and is so self-evident under modern conditions.

New processes working on an extended manufacturing scale are undoubtedly springing up on all sides, which owe their existence to the results of modern experimental investigation. These could not have come into existence on a basis of mere observation. They are direct results of an investigation conducted on original and definite lines. This method has given results which could never have been realised under the old *régimé*. The new method has supplemented the other, and has carried us further along the road of industrial success.

It is certain that the future belongs to the experimentalist. It is right to emphasise this in every way; but the value of observation in the past, as in the future, must be fully recognised by the investigator, who is to understand the past history of industrial progress. Observation rightly carried out will ever illumine the work of the investigator.

TRAINING IN METHODS OF RESEARCH.—The value of the experience gained by those engaged in original work is beyond dispute. In some quarters the advantage which the average student may secure by engaging in such work during his college course is regarded as uncertain. When considering this point it is well to remember that the actual conduct of original work must not be confused with an experimental knowledge of the general methods of conducting investigations in the research laboratory.

The absence of this knowledge may leave the worker at a disadvantage. The young investigator

entering the industrial world has to face problems calling for immediate investigation. In order that this position may be dealt with, a knowledge of certain procedure is essential. The training required for this work will be found on examination to be almost identical with that necessary for the conduct of original work. In both cases unknown conditions have to be considered. It is not at this stage that the phenomena dealt with are sufficiently defined for it to be known whether their investigation will entail the conduct of original research, or only call for the application of data published by previous investigators.

CHAPTER II.

Preliminary Survey and Selection of Subject Matter.

"Zeal without knowledge is like expedition to a man in the dark."—*Newton.*

The choice of subject matter will be influenced by the special qualifications of the investigator. A natural bent on the part of the student may generally be followed. Considerations connected with his future career, which may already be settled in direction, must also play a part in any selection. In the latter case the nature of the research and its object may be more easily determined. In the past, organic chemistry has claimed great attention. Speaking generally, there is a fashion in this as in most things. To-day, the attention of investigators is directed to many other branches, such as those dealing with investigations of the abnormal properties of colloids, catalysis, or electro-chemical investigation.

It is necessary to start with a definite aim, and to select a problem for investigation which seems to offer advantage in its solution. Investigation may take the shape of the study of a known reaction under new conditions, the confirmation of some law, or the search for a new one. A mere hunt after new compounds, on a plan equivalent to an addition, or subtraction, sum is to be deprecated. For this, coupled with the recognition of the substances produced, possibly represents investigation in its lowest terms. At the

same time the general usefulness of such work may, in the early stages of research, be accepted, where more important work is not available; and this criticism must not be taken as applying to the definite isolation and analysis of natural products. Research on elementary lines will often open out in unexpected directions, and disclose conditions which in themselves indicate the possibility of more important work. Its value in developing skill and resource is of a higher order than mere text-book reactions, where observation is the only factor involved.

The beginner need not be discouraged by comparatively simple conditions of working. These represent the working conditions of some of the greatest investigations of the past. Those of Griess, dealing with the action of nitrous acid on amines, led to an extraordinary development in organic chemistry. The study of this reaction, and the compounds produced by coupling, has given rise to theoretical and practical results of the highest order.

When the extent of the field of modern chemical investigation in its various branches is realised, it should not be a difficult task for the student to select a subject for consideration, and further investigation, and to make sure that any research arising out of the same shall have a definite aim from its inception. Specific instruction cannot be given in this matter. This belongs to the practical side of the question, but the suggestions made in these notes may be generally considered when a choice has not already been made.

The nature of the research must necessarily be considered in relation to the facilities which are available for carrying it out. Circumstances, and the position of the investigator, may therefore determine to a great extent the nature

of the research undertaken; and whether it will involve problems in pure or applied chemistry.

The importance of what has been described as residual phenomena should be carefully remembered. Sir W. Crookes has pointed out that these "may lead a man of disciplined mind and finished manipulative skill to the discovery of new elements, or new laws, and even new forces. Upon undrilled men these possibilities are simply thrown away. They are of the highest moment to the student."

Care must be taken to distinguish phenomena which only seem to point to apparent laws. No attempt can be made in these cases to draw general conclusions from them. At the same time a real exception may overturn the strongest theory; but interfering circumstances must be searched for very carefully when dealing with observations of this nature. It is often by comparing such exceptions that important discoveries are made. The methods of leading investigators should be studied. These at once indicate the extreme care which must be exercised in the conduct of research.

When it is fully realised that discovery is the result of a definite search, the value of the simplest piece of original work, correctly carried out, will be apparent, especially when it is regarded as a training for more important research. The investigator must realise the progressive nature of his work.

Preliminary Search for Past Records.—This must be undertaken in some detail before the actual research is started. The student must have definite knowledge of any work which has previously been undertaken in a similar direction. The source of available information under present conditions may be divided into four sections:—

(1) Text-books and Dictionaries.

(2) Journals of Chemical and other Societies.
(3) Technical and Semi-Technical Journals.
(4) Patent Literature.

Text-books are more useful for general work and in the preliminary stage of research. There is a growing tendency for these to be devoted to detail in special directions, and where this is the case, they become of importance to the corresponding investigator. Descriptions of a general nature should always be supplemented by a reference to the original communication, whenever this is possible. The details to be found there are often of first importance. They naturally cannot be included in text-books, where the compilers of such works have not, as a rule, the same object before them as the investigator.

Such works as Beilstein, or Dammer in his *Anorganisch Chemie und Chem. Technologie*, or Moissan's *Chimie Minerale* may be studied with advantage. The growing tendency to give reference to the original papers is a satisfactory one.

Reference to Journals.—It is always necessary to refer to any journals dealing specially with the subject in hand. Many of these which have come into being in recent years are confined to certain branches or subsections of the original science.

Thus it would be necessary for an investigator dealing with the chemistry of Colloids to carefully search the *Zeitschrift für Chemie und Industrie der Kolloide*, and when dealing with Tannins and their action, it would be necessary to refer to *Collegium*, the "official" journal connected with that branch of industrial research. In the case of dyeing, the *Revue Générale des Matières Colorantes*, the *Farber Zeitung*, and the *Journal of the Society of Dyers and Colourists* might be searched for definite information.

The International Catalogue of Science and the Indexes of the Royal Society's Proceedings should be carefully considered. Reference to a certain paper or communication will often by cross references open out a wide field for further information. The student must in this way make a special search for previous work. The leading journals to be consulted may perhaps be taken as those abstracted for the *Journal of the Chemical Society* and for the *Society of Chemical Industry*, respectively.

Résumés such as the monographs in Ahren's "Sammlung" are of special significance.

The preliminary search may also include the annual reports issued by the Chemical Society. For instance, the 1910 number contains articles covering the general progress in General and Physical Chemistry, Inorganic Chemistry, Physiological Chemistry, Agricultural Chemistry, Organic Chemistry, Stereochemistry, Analytical Chemistry, Vegetable Physiology, Mineralogical Chemistry, and Radioactivity. The general publications of the German and American Chemical Societies must also be consulted.

Besides the general papers appearing in the journals, the abstracts should be carefully considered. This search is facilitated when the collected index system is adopted, and which from its usefulness is destined to come into general use. The system of abstracting adopted by the leading journals has improved, and is now so complete that it may be used in the preliminary stage of an investigation with increased confidence. According to the latest information no fewer than one hundred and fifty journals are abstracted by the Society of Chemical Industry for their journal.

Patent Literature.—In some cases an important source of information will be found in the current patent literature as published in this country, Ger-

many, France and U.S.A., respectively. Copies of these patents may be seen at the Patent Office Library in Southampton Buildings, Chancery Lane, E.C., which is open from 10 to 10 o'clock daily. Many of the technical journals, such as that of the Society of Chemical Industry, abstract these patents in increasing numbers.

No likely source of information concerning past literature should be overlooked. This search may be regarded as part of the investigation, and the beginner must pay all attention to this matter, as it is one of first importance. It will reduce the possibility of an investigation being merely a repetition of previously published work to a minimum. The present advanced state of chemical investigation increases the value, and need of, this preliminary work.

When once the nature, or direction of, the research is determined, any references obtained in this manner should be carefully indexed, and a short abstract prepared dealing with their probable influence on the work under consideration.

This search, in conjunction with the selection of subject matter, may be regarded as the first step in the normal path of an investigation. These may be secured concurrently in some cases. The importance of method must be fully realised at this early stage, and should never be lost sight of until the research is completed and recorded in detail.

The beginner will naturally start work on a modest scale. The results to be looked for at this early stage are personal experience, training in actual manipulation, and an insight into the work of others as translated into actual practice. Minute attention to detail will bring with it method. The simplest piece of original investigation successfully carried out will bring with it confidence, which will develop, and give

ever increasing value to such work. The results obtained by an experienced investigator are to no small extent determined by the nature of his previous training.

Faraday, when reviewing his work up to the year 1832, divided it into good, moderate and bad. He valued the results on a personal basis, "because of the utility they have been to me, and none more than the bad, in pointing out the faults it became me to watch and avoid" (Tyndall, "Faraday as a Discoverer," page 38).

The student must never be discouraged by the time required to obtain experience and confidence. Faraday suggested that "it required twenty years of work to make a man in physical science, the previous period being one of infancy."

Investigation conducted on proper lines develops in a natural way, and with it the experience and power of the investigator. From the simplest research a new line of investigation may open out, and important results may be ultimately obtained. Tyndall considered that the real vocation of an investigator "consists of the incessant marriage of induction and deduction."

Personal Qualifications.—These are varied in their nature, and of great importance. They can only be considered in a general way. Curiosity, patience, critical power and industry are among them. How far these can be developed or even created by training is a matter for conjecture; but even where these are possessed, they must still be developed to their maximum.

The power of taking full advantage of observation, of being able to appreciate the value and significance of abnormal conditions as they arise, can only come with long experience and practice. It has been well said, that "every fact and every discovery casts a light beyond itself, and the ex-

tent to which this light is perceived depends upon the man. Training can certainly develop this natural faculty of observation and apply it to certain ends, even if it cannot supply it.

This power of observation should, therefore, be trained to its highest degree. Combined with the faculty of imagination, it is always exhibited by investigators who have made their mark in scientific research.

MANIPULATIVE SKILL. — This can only be secured by extended experience in the methods involved in such investigations. It is here that the practical training of the college course may be of such importance. Manipulative skill is of more value than elaboration of apparatus. Cavendish in a simple way obtained results indicating the proportion of oxygen in the air, which were practically identical with those obtained years afterwards by Bunsen and Regnault, when working with all the elaboration of apparatus then available.

At the same time there are natural limits to each specific method of working, and neither of these methods led to the isolation of the rarer constituents now known to be present in the air, although Cavendish's work clearly pointed to their existence.

The fact that Cavendish conducted the simplest operations on a quantitative basis may indicate the care required in successful investigation. He never prepared hydrogen without recording the amount of iron, or zinc, taken and the volume of gas generated; even when there was no immediate call for these observations. Faraday was equally careful, always repeating the experiments of others. "I am never able to make a fact my own without seeing it," he said. Also, "that he could trust a fact, but always cross-examine an assertion."

Many investigators find it advantageous to visualise in some way, the reactions involved in a research in its different stages. They are curious enough to form a mental picture, which may represent the nature of the reaction under consideration. Apart from any real significance in the effect produced, the plan is undoubtedly a useful one. It may be observed that this power of picture-making has been carried so far in some branches of research, that it seems to be the beginning and end of many investigations. Such endeavours must not be classed with the Kindergarten. They represent the romance of science, and symbolise advance from stage to stage. At the same time, they indicate the natural limitations of our methods of investigation.

In learning a language, it is necessary to think in the same before any real advance can be achieved, so in research a similar condition applies; the symbols used, crude as they may be, are a direct aid to success. It is often the chief aim of an investigator to secure this result. In its effect it may carry him over many a rough road. There may then be some consolation in a non-successful issue to an investigation; for when this is represented in its true light, and occurs under satisfactory conditions of working, it does not so much represent personal failure, as the limits of scientific investigation for the time being.

The use of elaborate apparatus is under some conditions essential. This may be necessary to the success of the investigation. Under ordinary circumstances this condition will not apply. The aim of the investigator should be to work under as simple conditions as are compatible with success.

Effect of Introduction of Instruments of Precision.—This has brought about far-reaching results. Lavoisier made use of the balance in 1778, and his investigations conducted with its aid ex-

ploded the philogeston theory, as a natural and inevitable consequence. The working out of some new apparatus often follows the discovery of some new scientific fact. It represents the practical application of the same. The invention of an instrument like the spectroscope, or the elaboration of the balance to meet the needs of chemical research, may almost be regarded as equivalent to an extension of one of the senses. The worker therefore endeavours to make use of such aids in his research. Under modern conditions this can generally be accomplished, as most of the modern colleges possess an adequate supply of these instruments. They are also present in many private laboratories.

Cost of Experimenting.—In the aggregate this is very large. The compilation by the Royal Society of mere titles and publication of the more important scientific investigations, cost nearly £10,000 up to the year 1879. It has been remarked that the cost of the researches themselves would amount to several millions, and that "these were made entirely at the expense of the investigators themselves, nearly all of whom were men of limited means."

Under modern conditions, very large sums are allocated in some cases by commercial firms, for the conduct of research. The preliminary work connected with the production of artificial indigo is said to have accounted for an expenditure of nearly a million sterling. In many directions large sums have been spent in investigating, on scientific lines, problems which may lead to an industrial application.

Investigations of this order often entail the use of complicated methods. Past experience has demonstrated that such operations, when brought to a successful issue, may have a value, which is represented by adequate financial gain.

This result is increasingly influencing the general progress of research. Many of the larger industrial laboratories dealing with such problems equal in their equipment, if they do not excel, those of many of the leading universities. It has been recently stated that a certain business combination in Germany employs no less than seven hundred chemists.[1]

Research conducted under such conditions and to such ends, entails details of an exacting nature, and demands manipulative skill and knowledge of a high order.

The conduct of such investigations offers a promising field to the investigator who has the necessary training, and knowledge of the methods to be employed. He must cultivate a scientific habit of thought, and combine this with a sound business insight into the working of industrial operations, and a practical knowledge of the results obtained, and aimed at, under such a system.

Generally speaking the investigator must have his mind stored with the chief facts and principles of science, he "must be able to imagine, invent, manipulate, observe, compare, and reason." (*Gore.*) With such a stock in trade the investigator can hardly fail to meet with success in the ever-widening field of original or applied research.

CHAPTER III.

General Procedure and Selection of Methods of Investigation.

"No scientific discovery can with any justice be considered as due to accident."—*Gore.*

Scheme of Procedure.—It is necessary to consider this in detail before actually starting work. As the course of the investigation develops, or takes a new direction, original methods and plans may be modified or altered, or, in extreme cases, rejected in favour of others. Where the investigation is of a definite nature such further treatment may be unnecessary; but this must not be looked for in cases where a research involves complicated conditions. Thus the investigator always has before him the question of possible improvements in manipulation, or alternate methods of working, and the influence these may have on the work in hand. Even in the case of the isolation of an alkaloid, or the preparation of a definite substance, the possibility of improvement in method should be constantly in mind.

When a point in theory is under consideration; or an investigation undertaken, entailing a series of changes, or measurements, which cannot be at the time explained or fully understood; or when changes in molecular constitution or complex laws have to be followed up, or investigated, subsequent alterations in procedure will almost always be necessary.

In industrial research the conditions are hardly less involved, for in that case phenomena which

are indefinite in their nature are constantly met with. These have to be constantly investigated, or at least controlled, before any real progress on the line originally determined upon is even possible.

Thus working conditions have often to be varied during the progress of an investigation, even when its ultimate object is fully disclosed from the commencement. Where this takes the direction of a search for new methods, or conditions, for arriving at a definite result, the research may chiefly consist in the determination of the best conditions to that end. The student may well put on one side such work for his more experienced years. In more or less simple research the beginner may often find himself face to face with conditions which seem to indicate the complete failure of his investigation. Sooner or later some way of dealing with such a position will probably be discovered, or a new method of attack devised. He should do all he can to hasten this result, and bring it within his own experience.

In dealing with such a position, past experience is the most valuable asset in determining the probable line of least resistance, and progress. No advantage can be gained by the beginner rushing into an elaborate research. Such work should be confined to problems which entail easy methods of procedure. This point must receive full consideration when the nature of the investigation is being determined in the first instance.

Chemical research may roughly be defined as belonging to the following types :—

(1) When known or general reactions are employed.

(2) When inventive power must be brought into play, and new methods, or conditions of working devised.

Examples of the first class should engage the attention of the young investigator. Their value, from a point of view of ultimate training and experience, may possibly be inferior, but from their nature they may be undertaken with more certainty by the beginner. They are better suited to his immediate requirements.

In organic chemistry the production of new compounds by known methods may be the chief aim in the investigation, although an examination of the conditions under which the reactions proceed may be of some importance. Research in this direction is sometimes hastened by its connection with commercial aims, as in the aniline dye industry. In organic research dealing with theory, the production of new compounds by familiar reactions may represent the practical side of the investigation. General reactions in this branch of chemistry are sometimes of great value, and the discovery of a new one may at any time have far-reaching results on the general progress of organic research.

This branch of chemistry has in the past been in general favour for research purposes. It is easily undertaken in the college laboratory. It is also a convenient introduction to more general investigation, or a suitable subject for continued work. When estimating its value in the former case it will be remembered that many experienced investigators, now working in other directions, obtained their early training in this branch of research.

The nature of research undertaken during the general period of training may be governed by certain considerations of a more or less personal nature. Subject to certain necessary restrictions, these may receive consideration when choosing a subject for investigation. The ultimate aim should

be one of general utility, and the research should involve a distinct advance in actual training and experience.

METHODS OF CARRYING OUT RESEARCH.—Following the selection of subject matter on such grounds as are indicated, the actual methods of investigation adopted represent the next point for consideration. These are determined and governed by the nature of the special conditions which have to be met. When new methods have to be devised, apparatus designed, or even invented, this preliminary step may in some cases be regarded as the chief feature of the research. The subsequent recording of results by its use may be considered as playing a secondary part.

It must always be remembered that when the ordinary apparatus of a well-fitted laboratory is sufficient, the use of specially-devised and constructed apparatus is undesirable. In organic research working conditions may generally be met in the ordinary laboratory. In working out new methods of analysis the same conditions may be looked for. When special conditions have to be met, involving more complicated methods of procedure, success will depend upon the necessary conditions being determined with as little delay as possible.

In advanced research, which in some branch or other should be the ultimate aim of all investigators, special apparatus is often necessary. For example, the successful termination of a research which entails a study of reactions occurring at a very high temperature, may depend upon the experimental conditions being met in a satisfactory manner. Special methods must then be employed in the registration of the physical conditions present at the time of the investigation.

Without the electrical furnace Moissan could

not have undertaken his important work on high temperature reactions. Without the vacuum-lined vessel many experiments at low temperatures would have been impossible, or only carried out with extreme difficulty. In some cases a piece of apparatus, or instrument of precision, may therefore be the determining factor in the investigation.

Research may therefore involve the use of :—

(1) The ordinary apparatus of the laboratory.
(2) Special, but already described apparatus obtainable in commerce.
(3) Apparatus which must be specially devised, or invented by the investigator.

Extended study and practical experience are necessary qualifications when working under the last conditions. For this reason the student will do well to follow intelligently the published records of such work, with as much care and detail as if he were engaged in the research himself. An opportunity of watching an investigation in actual progress should be always taken advantage of for a similar reason.

Referring to the first two cases, consideration must be given to the selection of the most suitable apparatus available; and in the order of their classification the aim should be to work under the simplest conditions. This will at the same time tend to reduce the experimental error to a minimum.

When the conditions under which an experienced investigator works are examined in detail, it will be found that in the majority of cases they conform to this rule. The simplest apparatus which will meet the necessary requirements is used. Even when new apparatus is devised it is often characterised by its apparent simplicity.

Speaking generally, an attempt should be made to start research, or work under research conditions, before leaving college, while a knowledge

of theory is still well in hand. If this is not possible, the student should leave with a determination to ultimately engage in such work, but in this case valuable time may be lost when the necessary experience has to be gained in after life. Thus a knowledge of actual working conditions rightly belongs to the college stage. Familiarity with the general conditions which surround such investigation and belong to it, is a certain aid to future success. A state of mind is engendered which persists, and is essential to ultimate success.

Another factor which operates in the same direction is observed in many cases. An enthusiasm has been developed in many institutions by certain teachers who have inspired their students with similar ideals, indicating by actual example the need for the inclusion of such work in the training of students, who must in their turn engage in such investigation in the ordinary course. By imparting their special methods of working, they have generally given to a direction the work of others. This influence has been a determining one in the past. Examples will occur to all. The formation of so-called "schools" is its outward expression. These have always been founded on a basis of original investigation.

Another influence is frequently present. This is not so generally understood, or discussed. In many ways it is hardly less far-reaching in its effect, but it is of an impersonal nature. It is felt by those who are in constant contact with operations proceeding on an industrial scale, with continuous regularity for long periods.

Its influence on the investigator is difficult to define, but those who have grasped its meaning are known as having a practical turn of mind. They possess a power of intuition and initiation in industrial research which is not often met

with in those who have not passed through this experience.

This training confers the quality of caution, combined with an instinct for working in practical directions. Such an experience frequently enables a man to outclass one with a superior theoretical knowledge. It brings with it confidence, and some additional qualifications which favourably influence the conduct of original work.

When this is fully recognised, as it will be one day, the relationship between industrial and pure chemistry will correspondingly improve. These two sections are but branches of the same science: the one is complementary to the other.

There is no real significance in reactions conducted on a ten gramme basis, which is not equally apparent, when they proceed on a scale measured in tons; nor is there any special magic, beyond that of convenience, in the glass beaker or the platinum boat, which is not equally present in the salt pan or the blast furnace.

The student should aim at a wide experience, and knowledge of a general nature, so that he may be equally at home in different branches of research. Experience of this order can alone make him a successful investigator under the conditions which must obtain in the future. He must take a wide view of his subject, and be prepared to follow up investigation in whatever direction it may take. This is a task of considerable difficulty, but one which must be met by the modern investigator.

CHAPTER IV.

Chemical and General Scientific Investigation.

"For the Pseudo-Chymist seeks gold, but the true Philosopher, Science, which is more precious than any gold."

At the present day theory is held of little account unless it conforms with such experimental evidence as may be available: past investigation to a great extent determines its natural limits. Under this essential condition the influence of theory on practice has been far reaching and beneficial. The value of theory is regarded as of such importance in certain directions, that investigations which do not involve some point in theory are regarded as occupying a lower plane.

Research which is connected with industry, or some practical application, is then ranked as of a secondary order. Under modern conditions this position may have to be reconsidered.

The condition that theory must fall into line with practice or be discarded, has limited false pretensions on the one hand, and on the other has given it additional value to the practical investigator. A full knowledge of the theory of any subject for the time being should thus be regarded as an essential factor in all investigation; full allowance being made for any tendency which may exist in certain directions to overload practice with theory. The latter in that case defeats its own end. The normal state must be one in which practice and theory advance hand in hand.

There can be no doubt as to the value of theory

which is sustained on a substantial basis of fact. This is demonstrated daily. The practical investigator will make all use of this important fact in the advancement in his investigations.

RESEARCH IN RELATION TO PURE SCIENCE.—In this case investigation is confined to the consideration of natural phenomena. It does not concern itself with practice, except where it incidentally deals with changes which actually play some part in industry.

Research of this order deals with the nature of natural phenomena, and an expression of the results observed in terms which cover the special requirements of the branch of science involved.

It deals with the investigation of phenomena which are only partly understood, examines past results in the light of more recent experience, and extends knowledge in every possible direction, determining for the time being its limits. Its programme is specific and self-contained. Any practical application of the results obtained is outside its sphere. It aims at a knowledge of the ultimate state and condition of matter, and its attendant phenomena.

Research of this nature is under modern conditions generally subsidised in some shape or form. It may be carried out at the University or College; it is generally confined to those able to conduct such work without the direct hope of pecuniary reward.

It is not correct to assume that the results obtained have no practical interest, or that they may not sooner or later have some definite value in the hands of the practical investigator. Thus a general consideration of the theoretical conclusions is of vital interest to the technical investigator, and incidentally such applications have an equal interest to the worker in pure science. They often confirm views on a more widely set area than can possibly be obtained in the laboratory.

It is therefore necessary for the practical man to

keep closely in touch with theory, and the worker in pure science to have some knowledge of the results obtained in its practical application, and use, and the way theory may be modified by more general experience.

Thus the investigator must have a special knowledge of general facts, so far as they may be expected to influence his results and work, and examine the conclusions which have been arrived at in any branch of science which may seem to be directly, or indirectly involved in his investigation.

The general question of this practical application and use of theory is therefore a most important one, as this extension must in many cases ultimately determine its actual value. Chemistry is essentially an experimental science, and it must, as in the past, justify its existence on the grounds of general utility, and not of theory. From the point of view of progress, the relationship between the different branches of investigation must therefore be as intimate as possible.

The value of research in pure science is supreme. It is directly responsible for progress along definite lines. It has set up a constantly changing system which has been followed in its natural development with a certainty of procedure which is based on a belief in the ultimate value of the methods involved.

In combination with theoretical speculation, it has secured a further advance in knowledge, which may be defined as of a less definite order. In effect this has secured a position for chemistry which has hardly been equalled in any other branch of science. No other branch of experimental work can be said to have escaped its influence. Its importance to industry is beyond all question.

It is impossible to judge the approximate value of theory as it exists under present conditions. At some time in the future, the benzene ring may have

less significance than a daisy chain, but it has made for progress. Speculations on space formulæ and the attendant models may be an equally inefficient application from an ultimate standpoint. They may belong to the childhood of science, but in spite of all that can be said in this direction, the value of such speculations is seen in the practical advancement which has followed in their train. Thus theory forms one of the most interesting branches of any experimental science. It plays a definite and essential part in the general scheme of progress.

Relation between Chemical and General Science.—This is increasingly intimate under modern conditions. Any advance in a special subject necessarily becomes of interest to many branches other than the one under which it receives classification. It may often throw unexpected light on investigations in seemingly quite other directions.

The development in experimental chemistry has been so widely spread, that the ever increasing volume of recorded data brings with it a natural tendency to specialisation on the part of the investigator. Thus the true relationship between the different branches of experimental science may be overlooked. The student will do well to remember that this tendency to specialise is not to be encouraged before it is forced upon the investigator. The effect of too early a specialisation is continually brought to mind by a study of some of the records of modern investigation.

This position may be regarded as the opportunity of the young investigator. The results obtained in comparatively new branches, like those of bio-chemistry, electro-chemistry, and others which might be mentioned, are demanding an ever-increasing recognition from investigators working in other directions. These inter-developments are setting up new con-

ditions, and increasing the available knowledge which may be brought to bear on any specific research, by establishing a more definite relationship between the physicist and chemist.

In this respect, the investigator will welcome the ever-growing list of text-books devoted to special subjects. In many cases, these afford a ready means for reference to the salient points in theory and practice connected with special branches of modern investigation. This new factor widens out the horizon for the worker by increasing the facility with which general information may be obtained.

A few examples may be considered here, which suggest themselves, in passing, as having reference to this special development.

The first one chosen is that of bio-chemistry. Meldola has pointed out, (*Chemical Synthesis of Vital Products,* 1904) that even if we have in the field of carbon chemistry produced thousands of compounds which do not, and probably never will be found to, exist in living organisms, there is no justification in assuming that we have reached a stage where it is unimportant whether an organic compound is producible by vital chemistry, or that the known laboratory methods are equivalents of the unknown vital ones.

A simple case will illustrate this. "The fundamental synthesis *par excellence*, in which carbon dioxide is absorbed by an organised compound and the product, or products, decomposed with the liberation of oxygen, is as yet without a laboratory parallel." In a similar way it may be claimed that although such actions as those due to enzymes may be imitated by laboratory methods, yet no hydrolysing agent of the nature of an enzyme has ever been synthesised.

It is therefore essential, that the chemist and

physiologist should work together. Their relative dependence is the watchword of modern investigation in this direction. Only in this way can the future of bio-chemistry be assured, and this science established on a firm basis. The subject is a fascinating one, and of great importance to the student in search of matter for further investigation.

In a similar way the proteins offer an ever widening field for research, as a reference to the Chemistry of the Proteins by Mann (1906) will readily indicate. Here the conditions are exceedingly complex, and an almost unexplored region is yet to be covered. Future developments in this direction cannot fail to be of a startling nature, and of equal importance to the physiologist as the chemist.

The subject of the alkaloids offers another field which may be expected to yield results of great practical and theoretical importance. A reference to vegetable alkaloids by Pictet and Biddle (1904), or to a series of volumes published in 1900, 1905, and 1908 respectively, under the title *Die Alkaloidchemie,* will give the investigator some indication of the scope of this branch of chemistry, and its present position.

In the same way, it is difficult to over-estimate the interest which catalysis, and the general reactions which are classified under this heading, offers to the investigator, especially when the recent developments in this direction are remembered. In its modern phrase it has been extended to organic chemistry. As practised at high temperatures by Sabatier and Sanderens and others, it can be practically utilised in many ways, as in processes involving reduction, hydration, oxidation, and elimination of halogen hydride, etc. On the industrial side, Ostwald has made practical use of this action in the manufacture of nitric acid. Its use in the manufacture of sulphuric acid is common know-

ledge. These interesting processes are being extended industrially. The possibilities have not been exhausted, in fact, developments of an increasingly important nature must continually be expected.

As the successful application of these methods generally turns upon attention to minute detail, systematic research is the only instrument which can advance our knowledge in this direction, especially as many of these changes are under certain conditions reversible ones. The theory is undeveloped, and the practical position may be regarded as almost virgin ground. The influence of third substances in minute quantity may alter the normal direction of the reaction, or may determine by their presence, or absence, the success of such processes from a commercial point of view.

In recent annual reports of the Chemical Society a general summary of results obtained in the domain of organic chemistry will be found.

"Unsaturation" offers a wide field for research. Also the relation between colour and constitution, which may throw light upon many other reactions, and help to explain the mechanism of chemical change, are matters of first importance.

Physical chemistry, in its different branches dealing with such subjects as the solution state, molecular weight, thermodynamics, chemical dynamics of homogeneous and heterogeneous systems, chemical equilibrium, and many other subjects has under modern enquiry developed to an amazing extent, but such investigation demands exact knowledge and the use of special apparatus before research can be undertaken with any advantage.

Stereo-chemistry, dealing as it does with space—as distinct from structural—formulæ has given rise to speculations of an advanced character. Some idea of its present scope may be gained by reference

to *Stereo-chemistry,* by A. W. Stewart (1907) in the *Text Books of Physical Chemistry* Series, where the phenomena of steric hindrance, relation between space formulæ and chemical properties, substitution and stability, and other equally important questions are dealt with.

The present position of organic chemistry is complex to a degree. In *Die Synthetisch organische Chemie der Neuzeit* (1908) Schmidt deals with the advance in synthetic organic chemistry. If the student will refer to Cohn's *Algemeine Gesichtspunkte der organischen Chemie,* he will find many hints which will be invaluable in the conduct of research in this direction. Beilstein's *Handburch der organischen Chemie* and Richter's *Lexicon der Kohenstoffverbindungen* are indispensable reference books for all points of detail.

Fischer's work has been reprinted in a series of publications dealing with the sugars, purines, and polypeptides respectively, and a study of his work and methods is particularly interesting to the student.

Enough has perhaps been said as to the importance of research in connection with theory and the practical results which have followed investigation on such lines. Whether by this means we shall ever arrive at the ultimate goal, which has been defined by Freer (*Introduction to Laehmann's Spirit of Organic Chemistry*) as a "perfect human knowledge by which from any given premiss the logical conclusion may be drawn with unerring accuracy," is impossible to surmise from the data available.

The student may regard with a sense of awe the increase in the number of important sub-sections of chemical research within the last decade. He may trace the rise of stereo-chemistry to the recorded results connected with optical activity, and a determined and definite search for an optically

active compound owing its asymmetry to the molecule alone, and not to an asymmetric carbon atom. As indicating the inter-relation between different branches of science, the relation of stereochemistry to physiology is a matter of first importance.

The whole question of the action of enzymes is also one which can hardly fail to offer the investigator a fruitful harvest to his labour. A study of recently published work will give an idea as to the aims and objects of this special work.

Recent developments are but the promise of a richer and far-reaching harvest in the future. This certain fact cannot fail to create within the young investigator's mind a deep enthusiasm, when the vast extent of yet unexplored ground to be covered, and the results which may be expected are realised.

There is hardly a science, or an art, which can reasonably expect to escape the attention of the chemist, or the influence of chemistry. This is seen in the fact, that physical science is but a latter day development of this science; and recently Prof. Rutherford has claimed that in electrical engineering the pioneers were the physical men. (*Eng. Sup. Times,* 20 Oct., 1910). New sciences spring up, and seemingly develop on original lines, only to be subsequently inter-related and closely woven into the general fabric, which, erected on a sure basis of research, is determining the future physical destiny of man.

CHAPTER V.

Application of Chemical Research to Industry.

"He that will not apply new remedies must expect new evils. They that reverence too much old things are but a scorn to the new."—*Francis Bacon.*

The effect of the development of chemical research in its application to industry is seen in the fact that the virtual control of certain industrial operations has passed to science. This is a characteristic feature of the age. It is hardly too much to claim that this condition must in time become a general one. It is difficult to call to mind any manufacture which would not benefit from such a change; for the preparation of raw materials and every subsequent stage of manufacture may certainly be influenced by such means. This is so evident, that it only calls for passing notice.

In some cases this influence may be directly observed in the product itself, as in high speed steel, artificial indigo, etc. In others, where the changes are connected with the details of works manipulation, and often kept secret from the knowledge of rival operators, the influence is not so evident to the public eye.

Some idea as to the scope of modern chemical research in its relation to industry may be gathered from the following sectional headings adopted by the Society of Chemical Industry for abstracting purposes. General Plant, Machinery, Fuel, Gas; Mineral Oils; Waxes; Destructive Distillation;

Heating, Lighting ; Tar and Tar Products ; Colouring Matters and Dyes ; Fibres, Textiles, Cellulose, Paper ; Bleaching, Dyeing, Printing, Finishing ; Acids, Alkalis, Salts ; Non-Metallic Elements ; Glass, Ceramics ; Building Materials ; Metals, Metallurgy ; Electro-Metallurgy ; Electro-Chemistry ; Fats, Oils, Waxes ; Paints, Pigments, Varnishes, Resins ; India-Rubber, Gutta-percha ; Leather, Bone, Glue ; Soils, Fertilisers ; Sugars, Starches, Germs, Fermentation ; Foods ; Water Purification, Sanitation ; Organic Products ; Medicinal Substances, Essential Oils ; Photographic Materials and Processes ; Explosives, Matches. These divisions indicate the main branches of industry which already entail chemical research, and investigation, in their development.

In addition to this direct influence on established industries, many new ones have been called into existence, as the result of chemical research in its widest sense. Some of these are already firmly established, and of great importance. The industry dealing with the fixation of atmospheric nitrogen bids fair to supply the world with cheap nitric acid, ammonia, nitrates and cyanides, urea, etc. The artificial silk industry has already supplied the markets with a cheap and efficient substitute for real silk. The artificial alizarin and indigo industries have reached a stage of fearless activity, and have profoundly modified the position of the corresponding natural products, having to an extent replaced them.

In all such cases the conditions of investigation and development are of an essentially different kind from those which are confined "*to constant speculation on the lines of a more rational theory*," but the general principles underlying the two branches of research are identical in their widest terms and conditions. The differences which exist are confined

to detail, and are in many cases chiefly due to the relative scale of working.

An ideal training is one which enables the investigator to work in both pure and applied chemistry. This can evidently be best secured when it deals with the underlying principles and practice, of research.

UTILITY OF INDUSTRIAL RESEARCH.—Financial advantage, and a correct solution to certain investigations, represents the ultimate aim in this case. The industrial advantage of a correct solution to these investigations must in some way be evident. The probable result of a successful issue may sometimes be estimated before the research is undertaken. Thus, the utility of a process for producing a reliable synthetic rubber at a cheap rate is self-evident. Such problems have therefore an interest to the capitalist. They are often considered from this definite standpoint by associations, individuals, or private firms.

Under modern conditions the success met with in many directions has been substantial. In the much advertised case of the aniline dye industry it has been found possible to establish laboratories in which a large staff of chemists are employed on research, from which important developments have resulted. Scientific investigation is in this, as in other cases, an essential factor to industrial success.

CONNECTION BETWEEN THEORY AND PRACTICE.—An industrial application may follow naturally on an investigation which in its inception and characteristics is only of theoretical importance. The development of the Mond nickel process from the original investigation of carbonyls is a case in point. The systematic study of the general properties of colloids, and their reactions, is known to have exercised a profound influence on certain industries. Another example which might be men-

tioned is the influence of the metallographic study of alloys and metals on the metal industry generally: Auer von Welsbach's work on rare earths in connection with the incandescent mantle industry may also be cited.

The development of the Mond process to its present commanding position in the industrial extraction of nickel is known to have presented immense difficulties which were at one time looked upon as almost insurmountable. Its successful manipulation on the large scale is one of the triumphs of chemical engineering.

The connection between investigation undertaken in connection with theory, and that of industrial investigation conducted on scientific lines is too evident to require further comment. The former occupies a definite and commanding position; the more so, as it has no immediate connection with direct gain of a financial nature.

The ultimate fusion of the relative interests of theory and practice, which must follow as a direct result of a closer relationship between the two sections, naturally leads to further developments. With this comes a further advance in the influence which science exercises over industry. Its influence in this direction is to-day self-evident. All that remains is to develop its latent-power to the greatest extent.

The present development of the gold industry of the Transvaal has been only possible through investigations conducted on the action of cyanides on metallic gold. Equally important developments in the textile industry have followed the study of the action of caustic soda on cellulose under varying conditions of strain.

In both cases, however, the working out of detail was the important factor. The solubility of gold in cyanide solution, and the action of

caustic soda on cotton were both known for years before any important practical application resulted. The extreme importance of an investigation being carried out scientifically, and to its natural limit, is thus demonstrated.

The object before the practical investigator (so far as the utilisation of the results of theory is concerned) is to reduce the period between discovery and its industrial application to a minimum.

The aim of the chemist is to achieve this in the shortest possible time, and secure the full advantage of such investigation. Many cases might be quoted where the direct influence of theory has alone given a clue to the solution of important problems in industry.

The general statement that all scientific knowledge will at some time be utilised, and have an influence on industrial developments, may be regarded as correct in its widest sense, especially when it is remembered that evidence of a negative character is sometimes almost as valuable as positive information. In industrial research it is often as useful to know what not to do, as the reverse.

It is obviously impossible to predict how soon knowledge may be usefully applied, and therefore any natural division between theoretical and industrial research should be reduced to its narrowest limit. This condition may best be met by the practical investigator having a sound working knowledge of theory.

When such a problem has to be undertaken, this influence must be considered in all directions possible : this condition applies equally in the case of industrial investigation, as in that of investigation in theory.

Scale of Working.—It is sometimes very difficult to decide the scale upon which the investigation shall be conducted. This is an important point

and one which will largely depend upon possible aims, and developments which may be looked for. It is generally found that processes worked out in the laboratory, with a view to their ultimate use on an industrial scale, have to be subsequently modified in many details. In industrial research other conditions apply to those observed when working in a laboratory, where results are obtained which are complete in themselves. In the face of this condition, the past experience and working conditions of the investigator will probably determine the actual scale on which the research is conducted.

The industrial chemist must have some knowledge of the general conditions involved, when laboratory investigation has to be extended to practice on the larger scale. Subsequent difficulties may often be obviated by working under correct conditions in the laboratory in the first place; and it is here that practical experience plays such an important part.

The natural difficulties met with in this transition stage have been lessened in some cases by the establishment of experimental work, operating on an intermediate scale, which may be considered as the equivalent of full-scale conditions. In this way the ultimate cost of production, and methods of procedure, may be accurately ascertained.

Experimental works dealing with processes connected with the fixation of atmospheric nitrogen may be seen in Norway. A similar one exists at Spandau for the purpose of establishing the value of processes, which have for their object the manufacture of the industrial scale of nitrogen products from cyanamide. Many other cases may be brought to mind of a similar nature.

Where the industrial position cannot be accurately estimated, this procedure is one which should be followed. Under modern conditions of

manufacture, new reactions are generally dealt with on an intermediate scale, especially when the conditions are exceptional or novel in their nature. This course is always a safe one to follow under any circumstances, and is to be generally recommended.

It is not possible on the present occasion to consider such matters in detail; or to more than touch upon examples in such procedure; but a few cases may be conveniently selected to give the student some indication as to their general nature.

A satisfactory example is perhaps that of the manufacture of hydrogen for commercial purposes. Preparation by the action of zinc has no longer any special interest. During a recent war it is said that this gas was prepared for balloon purposes from the action of concentrated caustic soda on aluminium shavings. Another process which has possibilities, and has been made use of, is the decomposition of calcium hydride. Hydrogen gas is passed into molten calcium in its preparation. Frank has proposed the method of passing water gas over calcium carbide with subsequent removal of oxides of carbon. The general method of preparation seems to be at present an electric one, but the action of steam on iron filings is said to have a future before it, especially when the resulting oxide is subsequently reduced by means of water gas, etc., and the process made a continuous one.

The difficulties of working these processes on a large scale cannot always be overcome in practice, and it is in such work that modern chemical engineering plays such an important part.

This example illustrates in a simple way the position a problem of this character may occupy at any intermediate stage in its development, and also when the investigation is finally completed in a satisfactory manner.

The work done at Mansfeld, in Germany, in

the direction of the treatment of copper ores may also be taken as a typical example. Augustin, working some sixty years ago, found that when finely crushed copper *mattes* were leached with sodium chloride the silver present was converted into chloride, and that this could be removed by solution in hot brine. Ziervogel subsequently found that by careful washing, coupled with a control of the temperature of the furnace, the silver could be converted into silver sulphate, which could then be washed out and recovered by precipitation on copper by the Augustin process. This process met with great success in Colorado, 2,770 tons of silver sulphate being recovered by this means at Argo alone. Another recent introduction at Mansfeld is the successful production of sulphuric acid from the converter gases produced in smelting the copper ore.

Again, in America, the Tenessee Copper Company are making 200,000 tons of tower acid per annum from the waste sulphur, while the Washoe Works of the Anaconda Company still discharges enough sulphur into the air to make 1,400,000 tons of acid per annum.

It has been claimed that with the exception of the apparatus used, metallurgical operations are essentially chemical in their nature. Many of the most important operations have to be conducted under supervision of trained chemists. It may be taken for granted, however, that in most cases of the treatment of ores, where any special difficulty is met with, that a very active co-operation of the chemist, miner, and metallurgist, is essential to success. Under such conditions ores can be worked, and give satisfactory profit, which would be "impossibles" in the absence of this mutual understanding and support.

In the past, many of the most promising pro-

cesses connected with metallurgy were invented by the "practical men," and subsequently chemists were occupied in determining their nature and control. The chemist has now, however, established a more definite position, and from the commencement assumed the direction of affairs in such investigations. Thus we see the gradual supplanting of the empirical method by that of experiment. This is probably an inevitable result in the case of a long continued development in any industry working under modern conditions.

The part played by chemistry in connection with metallurgy is certainly a determining one. The processes of reduction and oxidation, selective solution, and many others of equal importance, all demand a definite knowledge of chemical procedure. In fact, the processes themselves are strictly chemical ones. The results sometimes obtained are astonishing. In the case of the extraction of gold from its ores by cyanide solution, a saving of a penny per lb. in the price of cyanide means a further reduction in working expenses of £70,000 in the Johannesburg district alone.

The treatment of silver ores by this process also offers the greatest possibilities. The bi-sulphite treatment for zinc ores also suggests very important developments. Many other examples will occur to the student. Among these, the results obtained from the study of the properties of metals and alloys suggest that, in certain directions, improvements which can hardly be guessed at will be made in industrial practice as a result of extended work in this direction.

The financial gain offered for successful investigation is often great. The commercial treatment of arsenic-colbalt-nickel ores, for instance, holds out great possibilities.

In electro-chemistry the advance has been

phenomenal, and entirely new industries are being evolved. The original manufacture of calcium carbide has in its turn led to the production of cyanamides, which apart from their great value as fertilisers have, in their turn, given rise to the manufacture of ammonia, nitric acid and cyanides on an industrial scale. Developments in other directions have led to the direct fixation of nitric acid from the atmosphere. The production of calcium and sodium in large quantities, and many other substances also, has resulted from a study of the conditions of the electrical furnace as a means of inducing chemical action. This, in its turn, has led to the reduction, on a commercial scale, of metals like iron from its ores.

A definite study of the action of catalysis has led to results which are also destined to revolutionise many industries. Examples of this are already seen in the Deacon process of manufacturing nitric acid, and the Raschig method of making sulphuric acid. The field opened here is a wide one, and covers inorganic reactions as well as organic ones. The oxidation of naphthalene into phthalic acid, which has played so large a part in the manufacture of artificial indigo, is a case in point. Ostwald has pointed out (as quoted by Kennedy Duncan) that "if one considers that the acceleration of reactions by catalytic means, occurs without the expenditure of energy, and that in all technical work, including chemical, time is money, it is evident that the systematic use of catalysis may lead to far-reaching changes in technology." It is quite impossible, from our present knowledge, to suggest that any bounds can be set to future development in this direction, any more than in the case of electro-chemistry, or many others which might have been mentioned.

These few examples must serve to indicate the

part which chemical investigatión is playing in modern industry. It is remodelling procedure in industries of old standing; and, what is more important, supplying the necessary data for the establishment of a series of new ones. These owe their existence to experimental investigation, which is, in many cases, introducing into commerce new products, and processes, of great utility.

CHAPTER VI.

Research in Relation to Analysis.

"Every fact and every discovery casts a light beyond itself, and the extent to which this light is perceived depends upon the man."—*Gore.*

The influence of the application of modern theory to the methods of analysis has been of great importance. Until this was directly brought to bear on analysis the latter was incomplete, and to an extent empirical in its actual procedure.

Analysis was first placed upon a definite basis by Gay-Lussac and Berzelius. In the early development of chemistry, it played an important part. Regarded in latter years as an art rather than a science it ran a more or less isolated course, having little in common with the general development of theory. Rivot, Fresenius, and Rose practically limited themselves to detail in manipulation and the general conditions of working.

During more recent years this position has altogether changed. A detailed knowledge of the underlying principles of precipitation, etc., has modified the entire position, and analysis from its very nature has once more occupied an important place in its relation to the general theory. This change has been definitely described by Ostwald in "Die Wissenschaftlichen Grundlagen der Analytischen Chemie," Leipzig, 1908 (translated into English as "The Foundations of Analytical Chemistry," 1908).

By an application of the law of equilibrium to the

reactions involved, the conditions under which precipitation may be complete or incomplete were made evident, and the methods to be pursued in order to bring this operation to practical completion in the desired direction were indicated. This review of the question of analysis in the light of modern theory has caused analysis in its many reactions to take to itself an altogether new significance, and play a more important part in the science of chemistry, supplying an efficient method of confirmation for theory on a satisfactory scale, in a way which is brought to the notice of all workers in science.

No more satisfactory example of the advantage of the application of theory to practice could be found. It indicates in the most definite manner the advantage of examining processes, whether they be industrial or analytical, from a standpoint of theory.

More general information may be gained on this point by studying the "Theoretical Principles of the Methods of Analytical Chemistry" by Chesnau (translated into English by Lincoln and Carnham, 1910). In this work will be found indications of further research which is still necessary. It deals with such important matters as the influence of the physical state of precipitates, upon their purification by washing, irreversible reactions, double decomposition of salts, and the general study of the reactions which are met with when regarded from the "ionic" standpoint.

Thus in its modern aspect analytical chemistry occupies an increasingly important position in the general scheme of chemistry; and influences, by confirmation or otherwise, theory, and many of the conclusions arrived at in the domain of pure chemistry.

Analytical Methods and New Processes.—The results obtained by this application of theory may be regarded as perhaps a simple form of

research, and offer additional inducement to the young investigator, for his college training in theory may be of immediate value and importance. The scope of the literature on this subject is very voluminous, and a search will soon disclose some process in need of further investigation, or subject-matter for more or less original work.

A direct comparison of standard processes with others which are comparatively unknown, may naturally lead to an improvement in the latter in detail, and a confirmation of its limitations. Such work from its very nature is especially suitable for research under comparatively simple conditions, and for the general consideration of the young investigator.

A general view of the future position of analysis may be obtained by reference to the above-named books. Analysis, either volumetric or gravametric, offers a satisfactory field for research. A search for subject-matter, especially when the modern views are considered, will soon disclose directions in which further work is needed.

Many of the most important processes of to-day have been altered and modified for certain specific uses. The Kjeldahl process of estimating nitrogen may be instanced as an example.

The young analyst should always be on the look-out for possible improvements in methods. This search in itself cannot fail to make him a better worker, and give increased zest to his everyday work. The main object of such early investigation must be regarded as an educational one. The question of publication of results should not be considered by the beginner, except under expert advice. At the same time the results obtained should be assembled with the same care as if this was the object in view.

Obviously, defective or rejected, processes of

analysis, form a likely field for research. In these cases it may happen that the factors necessary to the successful working have not yet been appreciated. Such work which entails a careful search for the defects in the process may be regarded as altogether satisfactory for the student, especially if it is more or less simple in its nature and not obviously beyond the beginner's capacity.

Volumetric analysis, in particular, offers a suitable field for such attention. Much work remains to be done in connection with the indicators in simple acidemetry, as their actions are not yet fully understood. The presence of third substances may have a disturbing effect, the reason for which is not fully known.

This subject is worthy of the most careful study and consideration. So much depends upon the process of analysis resting on an unassailable basis. The experience gained is equally satisfactory in its nature and always useful. The results obtained may have a value outside that section of chemistry to which they often owe their origin.

Technical Analysis.—This is often of an empirical nature, and the investigation still to be undertaken in this direction possibly outweighs that already recorded. It is often of so involved a nature (owing to the conditions under which the processes have to be applied) that it offers special and specific difficulties. So great are these, that in certain cases, such as that of the analysis of tannins, purely empirical processes have the preference when they approach in their nature the working conditions of the industry itself. Thus we see in the case mentioned official sanction given to a process which is practically a reproduction of the working conditions on a small and easily manipulated scale. Hide, in a powdered form, is used as an absorbent, the tannin being taken up from an aqueous solution and

estimated by direct weighing. The conditions of analysis under circumstances such as these are very circumscribed, and the procedure is very complicated. The details in working which have been adopted to regulate the action of the processes involved are set out in a series of more, or less, arbitrary rules which are carried out by most analysts who have to deal with the valuation of tannins and tannin solutions.

In most cases the position is studied from the point of view of certain definite results, rather than absolute values. Modern science has much to say on the question of the elaboration of these details, and to the more advanced worker this work offers a varied and promising field for research.

These processes are capable of revision and improvement by systematic examination of detail, and this is constantly in progress under international agreement, or otherwise. As in the case of the estimation of tannins mentioned, the process as it stands is open to considerable objection by the chemist, but the trade still refuses to abandon it by substitution of other methods which give results not so easily calculated in terms of their trade significance.

Thus, when the beginner selects such processes for investigation, he must endeavour to determine the nature of these incidental effects, and seek to either eliminate, or control them. They may possibly be traced to errors caused by solubility, incomplete precipitation, the presence of third substances, etc., and the investigator must determine the nature of such defects by direct observation. In this respect the latest available knowledge on the general behaviour of third substances, the causes of incomplete precipitation, or the probable solution state of the reacting bodies, must be fully considered, and wherever possible, applied to the case under investigation.

The careful analyst makes discoveries of general importance, including that of new elements, and finds a source of inspiration in such materials as flue dust, residuals, and other seemingly impossible, or unlikely products.

Power of concentration, and a training of no mean order is required in such investigation ; and the results obtained under satisfactory conditions are of such definite value, that they receive increasing attention from all chemists.

CHAPTER VII.

General Conclusions.

"I know not what the world may think of my labours, but to myself I seem to have been only like a boy playing on the seashore, and diverting himself in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me."—*Newton.*

It is evident that the field of research is an ever-widening one. Each discovery is but a stepping-stone to others. Single observations may, as in the past, give rise to new sciences, called into existence to meet the new conditions, which have to be examined and recorded. As there is no finality to research, this condition will prevail equally in the future as in the past.

This natural development in the field of investigation is of great importance to the student. The increased tendency to sub-division, and the dividing up of science into a number of more or less water-tight compartments, for which there is obviously no counterpart in nature, is a defect which cannot be removed under present conditions. An examination of the results arrived at in one section, in comparison with those obtained in another, will hardly fail to indicate new lines for further investigation, and the young investigator should pay special attention to this point.

Knowledge is increased in this way. The application of the latest developments in colloidal chemistry to the theory and practice of dyeing, brewing, filtration, and the study of solutions and

their properties, are examples of this class of work. The student need only remember the importance of this application to the theory of photographic emulsions to immediately appreciate this point.

In the different branches of physical chemistry this interdependence is equally obvious and necessary.

The student who is trained to realise the inwardness of things rather than to act as a mere recorder of endless phenomena, in terms of certain methods of expression, will recognise this position by choosing a direction for investigation which holds out a reasonable promise of success.

Use of Mathematics.—This examination, when it involves a mathematical treatment, is a source of inspiration to many, if it is a corresponding trial to others. The conditions of research have been so modified of late years, that it is almost impossible for the investigator to carry on his work in a satisfactory manner without a working knowledge of mathematics. This has not been sufficiently recognised in the past. The methods of teaching this subject have also been in many cases so academic, that the student has generally failed to appreciate the importance of its practical application.

The far-reaching effect of the application of mathematics to experimental science is obvious. It is impossible to consider certain branches of chemistry without it. Its extended use in the science of engineering, or in physics, will be a constant reminder to the chemist of its practical value.

The statement has been generally made, that from his method of thought, the chemist can never be a transcendental mathematician. This may or may not be so, but the general investigator has no such need before him. He must be content with a sufficient working knowledge of the practical

side of mathematics. The worker who has not this knowledge may be referenced in the first instance to a Course of Practical Mathematics by Saxelby, or to Higher Mathematics for Chemical Students by Partington. Either of these will at once indicate that, within certain limits, the subject can be treated in a manner which is well within the grasp of any chemist, and also that one cannot fail to gain advantage from a working knowledge of this subject.

A certain want of understanding which exists between the workers in chemistry and physics may be to an extent due to the fact that they often, in the absence of a common use of mathematics, employ different methods to express results.

Methods of Recording Results. — Great importance should be attached to the registration of all references to the work in hand. Nothing is more annoying than the search for material, which is only generally remembered as being in print. This record should cover as extensive a field as possible, on both the theoretical and practical sides. All such references must be conveniently classified, preferably by card index, rather than by note-book system. They must be kept in a convenient form for future reference. In a few years this source of information becomes one of great value. A note-book for immediate use, and such a system of registration as some form of alphabetically-arranged record, or card index, is a necessary condition to systematic investigation.

It is essential that all observations, and any provisional conclusions based upon them, should be immediately registered. At certain stated intervals in the progress of the investigations these must be closely examined, notes written up, and the influence of any further results obtained on the direction of the research carefully observed, and any possible developments arising out of them

considered. This procedure saves much time and secures a systematic registration of results. This is a matter of importance, and an absolutely necessary condition to systematic work.

It is interesting to note that Faraday, who is recognised as probably the most precise investigator of the nineteenth century, had (according to Tyndall), as his most prominent characteristic, a sense of order which "ran like a luminous beam through all the transactions of life." His notes on this subject were found, on examination, to be numbered, the last paragraph being registered as No. 16,041.

PUBLICATION OF RESULTS.—This subject raises considerations of great moment to the investigator. When research work is conducted to a successful issue in a college, or university, it is nearly always published. In other cases publication may defeat the whole object of the research unless, at the same time, protection by patent is obtained.

Publication may take place through the medium of the recognised societies, in which case the communication is submitted to the Secretary for consideration by the Publication Committee. One obvious advantage of this method is that the communication may be read before the members and discussed.

The third method of direct publication is in the form of a monograph, treatise, book, or pamphlet. This is the method least often adopted in this country, owing to the question of personal expense and distribution.

PROTECTION BY PATENT.—Closely connected with the question of publication is that of protection by letters patent. This only applies to a matter which has an industrial application, as an abstract idea cannot be protected. The only recognition for work of a theoretical nature is by publication.

The question of publication by patent under

which the State grants a monopoly of user under certain defined conditions is one which must be decided in consultation with a patent agent. A provisional protection may be granted for six or seven months in this country for a nominal sum, and this does not entail publication, if the patent is not completed.

It may be advisable in certain cases to apply in the first instance for the German patent. It will be remembered that a special technical commission in that country examines all patents for novelty and previous publication. In this country the search is confined to English patents for the last fifty years.

The stage at which a patent should be taken out is a matter which demands close attention. If protection is obtained before the details have been worked out sufficiently for the process to be a workable one, its value is correspondingly small. In this respect the English Patent Office offers certain advantages by granting provisional protection. During the subsequent period of six months, the detail of the invention may be embodied by a final specification.

In modern practice it may happen that only part of the invention is actually patented and certain details remain secret. This is a matter which naturally demands special knowledge and involves questions of general policy.

The value of such rights to the investigator is difficult to determine. This may depend upon other considerations than that of the importance of the research. Utility is a matter of chief concern, and is a necessary qualification from the legal standpoint.

Facilities for Research in this Country.—It has been held in the past, that these have not been generally available, and it may be argued that this has

been a correct assumption. Many of the provincial universities, however, now advertise facilities for research, and the Royal Society and the Chemical Society have at their disposal limited funds which they disburse by way of grants, prizes, scholarships, etc. Research is also conducted at such institutions as the National Physical Laboratory, the Royal Institution, and certain other research stations.

Some of the scientific and technical societies form committees to determine certain points by investigation. For instance, the Institute of Gas Engineers has appointed a Gas Heating Committee, which reports from time to time (see *J. Gas Lighting*, 1910, *2*, 810), and the Institute of Metals is dealing with the corrosion of metals in a similar way.

The Government offices also from time to time appoint committees to deal with points which more or less involve chemical investigation (see *Times Eng. Sup.*, September 21st, 1910). The publications of the Bureau of Mines at Washington, U.S.A., dealing with technical researches and progress are also of considerable importance.

Some of the more modern universities, as, for example, that of Sheffield (*Times Eng. Sup.*, October 26th, 1910) deal in a similar manner with investigation of more or less technical importance. Thus in the case mentioned the Applied Science Committee has arranged that any new processes brought forward may be tested in the University on a manufacturing scale before any number of manufacturers adopt it. When, therefore, the general question is asked, whether it is advisable for the student or general chemist to engage in research, the answer must depend upon certain conditions which cover his training and knowledge of chemistry, natural adaptability, and facility for engaging in such work. The opportunity and time for conducting or engaging in such investigation may generally be

met even when the operator is engaged in practical work.

The beginner must determine how far he is able to conform to certain necessary conditions before attempting such work. Given favourable conditions, much will depend upon the nature of the proposed investigation. In some cases the chances of success are possibly more satisfactory when carried out in one of the recognised colleges, but (according to Gore) only if the professor is an initiator, and can carry on such work, and if he actually engages in the same with the student.

On the other hand, it is certain that there are many successful investigators who have not worked under these conditions, and evidence can be advanced which indicates that in the majority of cases, industrial research can hardly be expected to originate in the college itself. It so often happens, that it owes its origin to observation made under practical working conditions.

In many cases, as in the electro-chemical and several other modern industries which owe their existence to research, investigation has been carried on by certain industrial organisations on a scale which could not have been undertaken under our present college system. The results obtained have been of the greatest possible advantage to theory, as well as practice. Such laboratories are said to be in every way equal, and in some cases even superior, to those of the colleges and universities.

This relative value of research conducted under such different conditions is difficult to decide. This can only be settled by a more thorough investigation into the subject than can be undertaken on the present occasion. Conditions are rapidly changing in our colleges, and to this extent the position is being correspondingly modified.

Considering the amount of research that is

carried out by independent investigators, the condition that it must be carried out in the college or university has not been proved to be essential. At the same time there is much research which requires the aid of complicated apparatus. For this, and other reasons, it may be best carried out at such institutions, but a certain section of it must remain outside the range of the college requirements or programme and altogether beyond their financial means. It may, therefore, be necessary at some future time to reconsider the available facilities offered for such research work in the institutions of this country, and to determine their natural limitations and scope, and possibly to secure conditions of working which will facilitate a further advance in the required direction. It is possible that the time has not yet arrived when such a step can be taken with any degree of certainty. That this time will come in the natural development of scientific investigation is fairly certain. In the meantime it may be remembered that an extraordinary advance has taken place during the last decade in this country in the facilities for research.

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